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Tamper-Indicating Devices and Safeguards Seals Evaluation Test Report

Volume II

Patrick R. V. Horton, Ivan G. Waddoups

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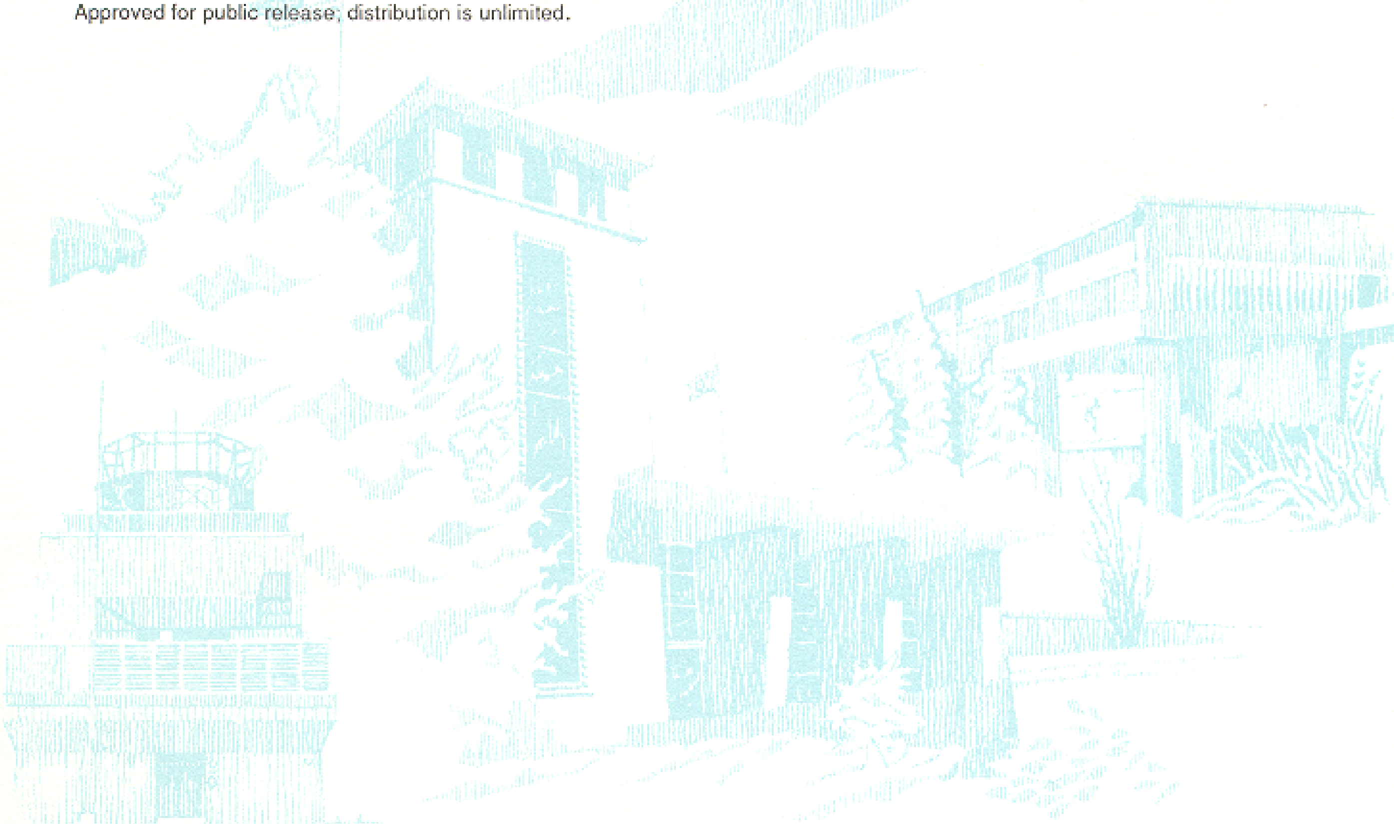

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Tamper-Indicating Devices and Safeguard Seals Evaluation Test Report

Volume II

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Abstract

Volume I was based on a survey and an evaluation of seals that are used as tamper-indicating devices at DOE facilities. For that evaluation, currently available seals were physically and environmentally evaluated under two broad categories: handling durability and tamper resistance. Our study indicated that the environmental testing had no negative effects on the results of the mechanical tests. In Volume II, we evaluate some loop, fiber optic loop, and pressure-sensitive seals that are not used at DOE facilities. However, we continue to focus on qualities required by DOE: durability and tamper resistance. The seals are comparatively rated, and recommendations are made for using currently available seals and new tamper-indicating device technology.

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Volume II

1. Introduction

1.1 Purpose. The purpose of this effort was to evaluate both new technology seals and vendor seals not currently in use at DOE facilities. The project's ultimate goal is to recommend those seals that are best suited for use within the DOE Complex. In this report, we provide general information on how the different seals are used, describe the tests conducted in the Sandia evaluation, summarize our test results, and document our recommendations.

1.2 Background. Some DOE Safeguards and Security Inspections resulted in concerns relative to seals currently used to protect and monitor special nuclear materials (SNM). In this report, the terms seal and tamper-indicating device are synonymous and will be used interchangeably. The tamper-indicating devices commonly used are one of two types: the pressure-sensitive seal or the loop seal . These seals are either placed on containers that store SNM or on smaller containers that are placed inside larger containers.

Typically, large containers are painted and consist of 5-, 10-, 30-, or 55-gallon drums with closure-locking collars. Smaller containers are plated three-gallon lard cans and five-gallon paint cans. The smallest containers are plated 1/8-gallon to one gallon fruit cans and 1 gallon paint cans.

When wooden containers are used, the pressure senitive seal is placed on metal-locking plates. This is necessary because the adhesive currently used does not consistently adhere well to wooden surfaces. As an option, loop seals can be attached to the metal tie-straps by drilling holes in the straps.

Sealed SNM containers are stored in a vault under two-person access rules. This rule requires that two knowledgeable individuals be in attendance and within line-of-sight of each other at all times while containers with the accountable material are accessible.

1.3 Survey. Sandia mailed a questionnaire in 1991 to DOE facilities to determine their requirements and how they were currently using tamper indicating deviceS. The questionnaire asked the following questions:

- What type and model of seals do you currently use?
- Who is the manufacturer?
- What is the application / usage, and how many do you use per year?
- What vulnerabilities are you aware of?
- What are the results of your evaluation?

After receiving this information, we contacted vendors who supplied us with literature and samples of their applicable seals.

Results of the survey indicated that DOE is currently using seals from nine manufacturers; eight were identified and one was unknown. The survey also showed that 11 different types of tamper indicating devices were used at the 18 facilities within the DOE Complex. Sandia selected five different pressure senitive seals and four loop seals from the survey, and these were tested in Phase I. Two additional manufacturers' pressure senitive seals were added to the test group which gave a total of seven pressure senitive seal manufacturers. Phase II testing included four other pressure senitive seals and three other loop seals which seemed to have promise but which were not being used in DOE applications.

The pressure senitive seals and loop seals evaluated in Phase I and Phase II are shown below in Tables 1 and 2. Phase I testing was documented in Volume 1; Phase II is presented in this document.

Table 1. The Pressure Senitive Seals and Loop Seals Evaluated During Phase I

Pressure-Sensitive Seal MANUFACTURERS			**Loop Seal MANUFACTURERS**	
Avery ^{DOE}	-paper		American Casting & Manufacturing ^{DOE}	
Advantage ^{DOE}	-mylar			-E Cup w/wire
Advertape	-vinyl		E.J. Brooks ^{DOE}	-Griploc
Designer ^{DOE}	-vinyl		Masterlock ^{DOE}	-Padlock
Tyden	-mylar		PCI (Product Consultant International) ^{DOE}	-Cable lock
Valmark ^{DOE}	-vinyl			
York ^{DOE}	-mylar			

Note: *Manufacturer* ^{DOE} = seals currently being used at DOE facilities

Table 2. The Pressure Senitive Seals and Loop Seals Evaluated During Phase II

Pressure-Sensitive Seal MANUFACTURERS		Loop Seal MANUFACTURERS
3M	**TEMTEC**	**Aquila Technologies**
Confirm -vinyl(inner layer) -Alkyd Polyester (outer layer)	*Security Seal* -acetate(inner layer) -flexographic ink (outer coating)	*Cobra Seal* -fiber optic cable -translucent plastic body
		E. J. Brooks
		Fiber-Lock -fiber optic cable -clear plastic body
American Banknote	**Tyden**	**E.J. Brooks**
Holographic -Mylar, two layer (inner layer, color) (outer layer, clear)	*WatchWord* -Mylar, single layer (interior, color coated) (exterior, satin finished)	*Multi-Lok* -aircraft cable -alloy locking body

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2. Specifications and Test Parameters

2.1 Tamper-Indicating Device Specifications. To qualify for DOE facilities, tamper-indicating devices must meet the following specifications:

- reasonable cost,
- resistance to environmental conditions (must remain intact, readable, and viable for at least two years subsequent to application),
- verification of seal serial number and integrity,
- ability to withstand handling,
- ability to indicate any attempt to tamper with the device,
- relative ease and speed of application,
- ability to fit and adhere to a variety of containers and their surface materials.

2.2 Test Parameters: The seals are expected to be used primarily in protected environments, such as inside buildings or transport vehicles. There may be brief periods when they are exposed to the outside elements. Most of the conditions specified for the tests we conducted are taken from MIL-STD-810D, July 19,1983. In this document, the military standard will be referred to as 810D and the method and section in the document will be provided.

The tests include a control group, a radiation exposure group, and a high temperature / high humidity group. The control group consists of tamper indicating devices that are tested without previously being subjected to environmental testing. The radiation exposure group is tested after radiation exposure. Our previous testing of similar seals resulted in no observable differences between the mechanical testing performed on control groups and the testing conducted on the high temperature / high humidity groups. Since these new seals use the same acrylic adhesive and similar substrate materials as those previously tested, it was concluded that mechanically testing the new seals would not yield any significant information. Therefore, mechanical testing was not conducted on these new seals.

2.2.1 Pressure Senitive Seal Testing. Three sets of coupons representing DOE facilities' container surface materials (stainless steel, enamel-coated steel, and polyethylene) were procured for testing the pressure senitive seals. The pressure senitive seals were placed on the coupons 24 hours prior to all testing, as recommended by acrylic adhesive manufacturers, to allow for adhesive curing. Using the coupons, the pressure senitive seals were subjected to the following environmental and mechanical tests:

- 20-day high temperature / high humidity test
- drop shock test
- erasing tests
- peeling tests

- radiation tests
- shearing tests
- solvent tests
- vibration tests

2.2.2 Loop Seal Testing. The loop seals were subjected to the following tests:

- 20-day high temperature / high humidity test
- 5-pound drop test
- 50-pound, 1-minute pull test
- drop shock test
- radiation tests
- vibration tests

3. Pressure-Sensitive Seals

3.1 3M's 1700 Series Confirm Seal. As indicated earlier, our market survey identified additional seals which could be applicable to DOE needs. This section describes four seals we concluded would be likely candidates for those applications. The Confirm™ Automobile Security Labeling System is advertised as a counterfeit and tamper-resistant seal developed for automobile manufacturers. The seal (Figure 1) is used to attach vehicle identification numbers (VIN) to new automobile components. The Confirm labeling system was designed to assist automobile manufacturers in complying with the U.S. Motor Vehicle Theft Reduction Act of 1984. This seal (2 x 4 inches) includes an outer coat (alkyd polyester) that is a very thin, translucent, onionskin-type pliable coating. This coating, which has incorporated into it a retroreflective Triskelions' ® image (logo) of the 3M trademark, has the serial number printed on its surface. This image is nearly invisible to the naked eye. When viewed with a special light viewer, the image looks similar to cat eye technology products used in reflective fabrics. The seal is well designed for resistance to tampering and counterfeiting. The onionskin is very delicate and the vinyl undercoat is thicker than the vinyl seals discussed in Volume I. The vinyl undercoat has a U-shape configuration and the onionskin outercoat covers the entire U-shape undercoat forming a rectangular shape. This configuration seems to be more durable than that of the vinyl and paper seals. In addition, the alkyd polyester configuration offers an area of delicacy in the void area of the U-shape.

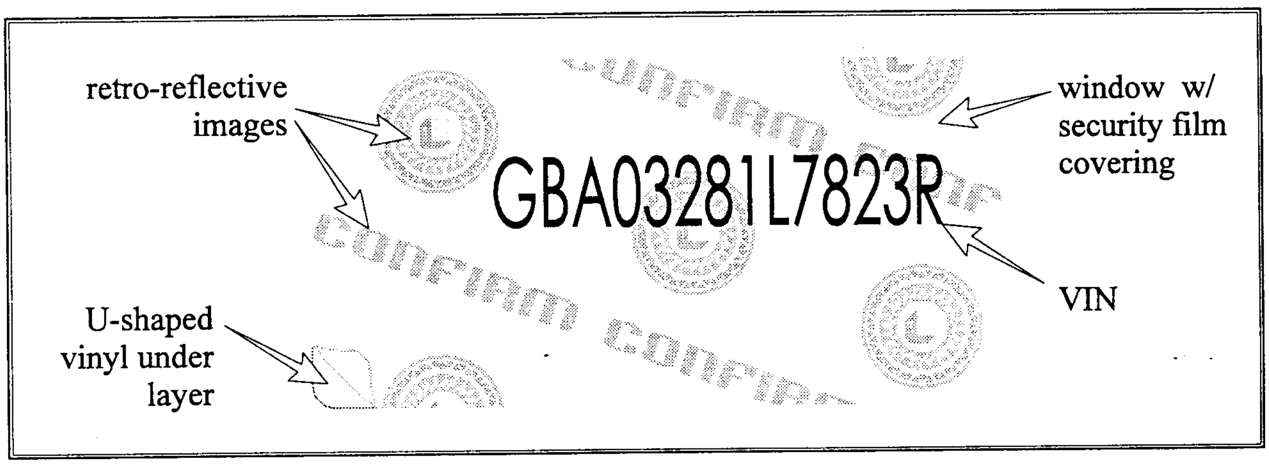

Figure 1. 3M Confirm Seal

3.2 American Bank Note (ABN) Holographic Seal. ABN provided Sandia with seals they custom made at our request. ABN does not normally make seals for the type of applications DOE facilities use. They provide the holographic seal technology for credit cards and currencies. ABN used a limited amount of existing credit card holographic stock to make seals shown in Figure 2, per our specifications (1 x 13 inches) and then donated the seals to Sandia for test and evaluation. Unfortunately, the quality control of the seal assemblies was not what we have experienced with other manufacturers and venders. However, the seal did quite well considering the short turn-around time requested and the new application for which the product was being used. At times, we experienced difficulty in removing the seal from the clear coat backings. Also, we sometimes inadvertently removed the clear coat of the seal instead of the bottom clear coat. Fortunately, all other mylar seals we tested came with a paper-type backing that is more user friendly. The holograms, however, were of excellent quality and so were the acrylic adhesives.

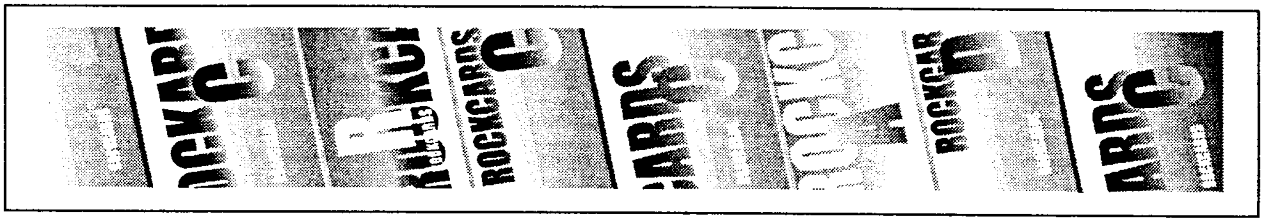

Figure 2. American Bank Note - Holographic Seal

3.3 <u>TEMTEC Security Seal</u>. The TEMTEC seal (Figure 3) is a one-inch wide, serrated-edged acetate seal with an outer imprintable dye coat. The serrated-edge feature makes tampering quite difficult, compared to the typical straight-edge paper and vinyl seals previously tested. When there is an attempt to tamper with the seal's acrylic adhesive by using solvents, the adhesive's reddish-pink dye coat bleeds. The TEMTEC Evidence Tape is manufactured for use in securing evidence bags and boxes. It is a one-inch wide pressure senitive seal that comes in a continuous roll of 84-feet.

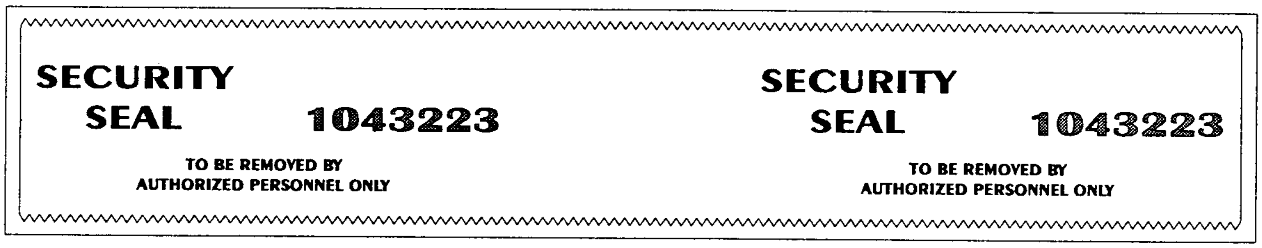

Figure 3. TEMTEC - Evidence Tape Seal

3.4 Tyden WatchWord Seal. The seal logo ("WatchWord") is imprinted on the seals from Tyden. The dimensions of the seal (Figure 4) are .5 x 2.5 inches. There is also a serial number printed on a satin finish coating on top of a Mylar clear coat. The color coat has the company logo printed on it. When the seal is peeled off a container surface, the word "void" bubbles up and separates from the rest of the acrylic-adhered color coat. If attempts are made to reapply the seal, "void" takes on a three dimensional appearance. Unlike the other mylar seals tested, the Tyden seal uses only one mylar layer. The top surface of the mylar has an opaque satin finish applied to it where the text and serial numbers are printed. Careless solvent attack will damage the satin finish and the text printing on it. This adds a level of tamper resistance slightly above other mylar seals tested.

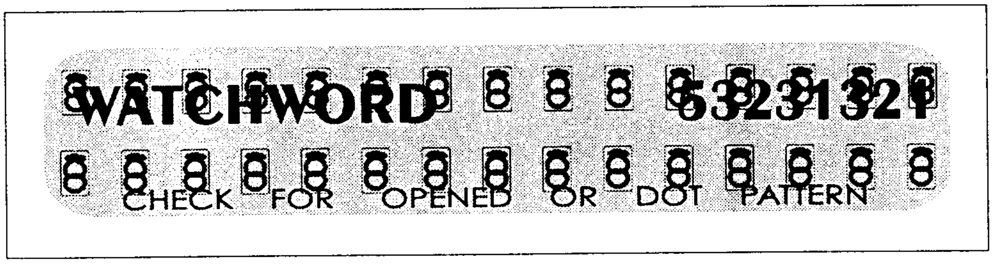

Figure 4. Tyden - WatchWord Seal

The WatchWord received for testing was .5 x 2.25 inches. When conducting mechanical testing (peel, shear, drop, etc.), two seals were placed side by side to provide the one inch-wide surface required.

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4. Pressure-Sensitive Seal Testing

Pressure-sensitive seal testing subjected the seals to a peel, shear, and solvent test. These tests were conducted using seals from each of the four manufacturers that were applied to polyethylene, enamel-painted, and stainless-steel coupons.

4.1 <u>Peel Test</u>. The peel test measures the ability of the pressure-sensitive seal to adhere to various container surface materials.

In the peel group, 1 x 7.125 inch seals were placed across the center of a single coupon. The pressure-sensitive seal extended beyond the edge of the coupon (Figure 5). The nonstick paper backing was left on approximately 4.25 inches of the length of the pressure-sensitive seal (for gripping purposes). Three seals of each type were tested.

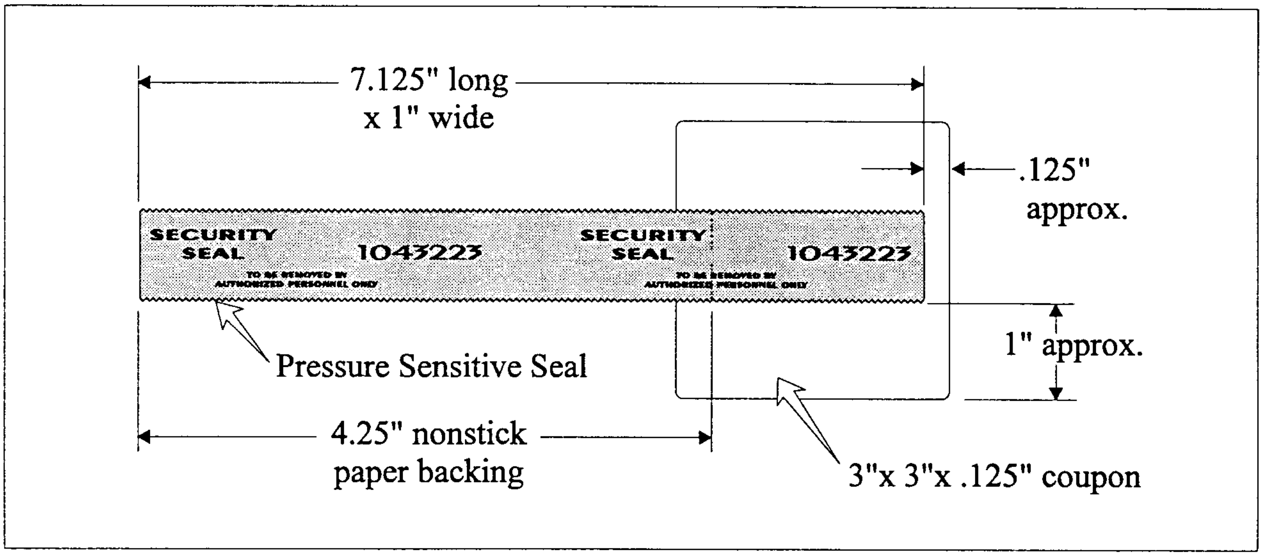


Figure 5. Peel Test Configuration

Table 3 shows the results of the peel tests that were all conducted at room temperature. In all of these tests, the seal's material, not the adhesive, failed. There are some differences in the results for the radiation and control groups, but we judge those differences to be relatively unimportant as far as either degrading or improving seal performance.

Table 3. Peel Test Results

Pressure-Sensitive Seals	Substrate (coupon)	Environmental Factors	Average Point of Failure in Pounds	Comments
3M Confirm (1.43)[7]	painted surface	control	2.0	note 1
		radiation	1.9	note 1
	polyethylene	control	0.8	note 2
		radiation	0.9	note 2
	stainless steel	control	1.7	note 2
		radiation	1.3	note 2
ABN Holographic (1.13)[7]	painted surface	control	1.2	note 3
		radiation	1.4	note 3
	polyethylene	control	0.8	note 3
		radiation	1.0	note 3
	stainless steel	control	1.2	note 3
		radiation	1.2	note 3
TEMTEC Security Seal (1.06)[7]	painted surface	control	1.3	note 4
		radiation	0.8	note 4
	polyethylene	control	0.7	note 4
		radiation	0.5	note 4
	stainless steel	control	1.7	note 4
		radiation	1.4	note 5
Tyden WatchWord (0.9)[7]	painted surface	control	0.9	note 6
		radiation	1.0	note 6
	polyethylene	control	1.0	note 6
		radiation	0.8	note 6
	stainless steel	control	0.8	note 6
		radiation	0.9	note 6

note:

1. Strength with onionskin peeling.
2. 3M outer coat Alkyd Polyester (referred to as "onionskin") did not peel.
3. Peeled top clear film from foil.
4. Peeled completely off.
5. Peeled slightly, then tore.
6. Peeled leaving dots and the word "opened" on substrate.
7. Average point of failure for all tests in pounds.

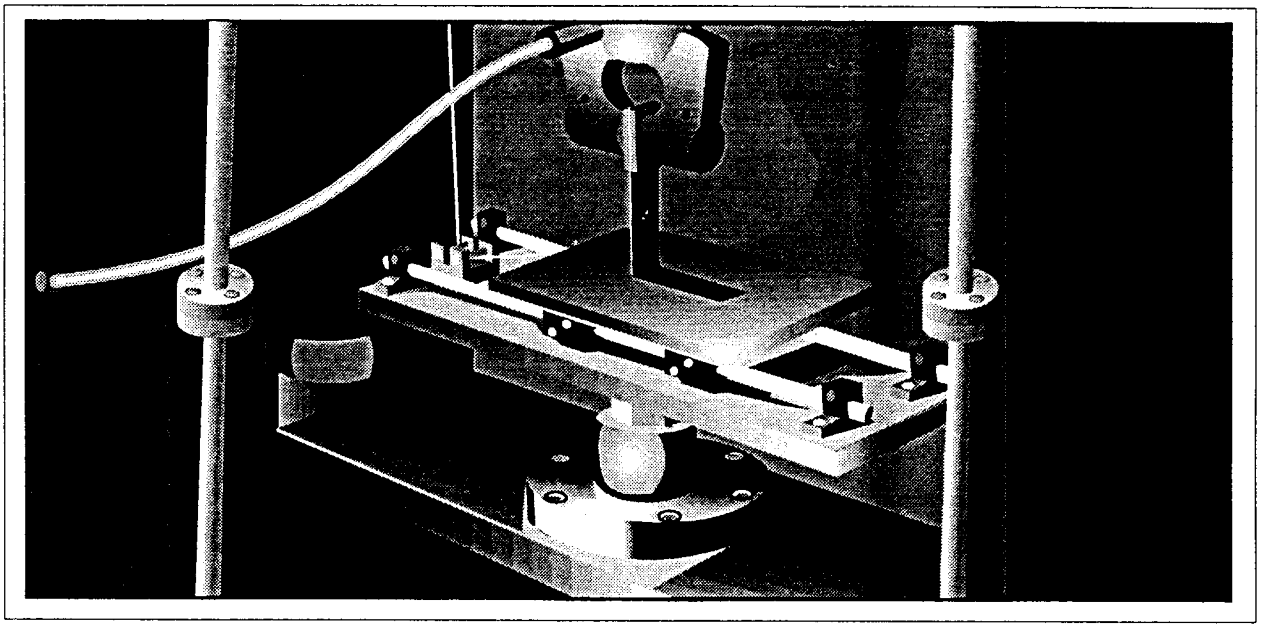


Figure 6. Peel Test Setup

The peel test (Figure 6) was performed using an Instron® 1125 linear tensile tester.

4.2 <u>Shear Test</u>. The shear test measures the adhesive ability of the pressure-sensitive seal and the strength of the pressure-sensitive seal material.

In the shear group two coupons (Figure 7) were placed end-to-end. Then, 1 x .5 inch seals were adhered across the center of two coupons. An approximate .5-inch space was left at each end of the coupons to allow for mechanical gripping during shear testing. Due to the fragile state of some of the seals, the pressure-sensitive seals were placed on both sides of the butted coupons to balance and strengthen the assemblies. This was done for each of the three groups of coupons.

All shear testing was performed at room temperature. The results of the tests are shown in Table 4. In all of these tests, the seals material, not the adhesive, failed. There are some differences in the results for the radiation and control groups, but we judge those differences to be relatively unimportant as far as either degrading or improving seal performance.

The shear test (Figure 8) was performed using an Instron® 1125 linear tensile tester.

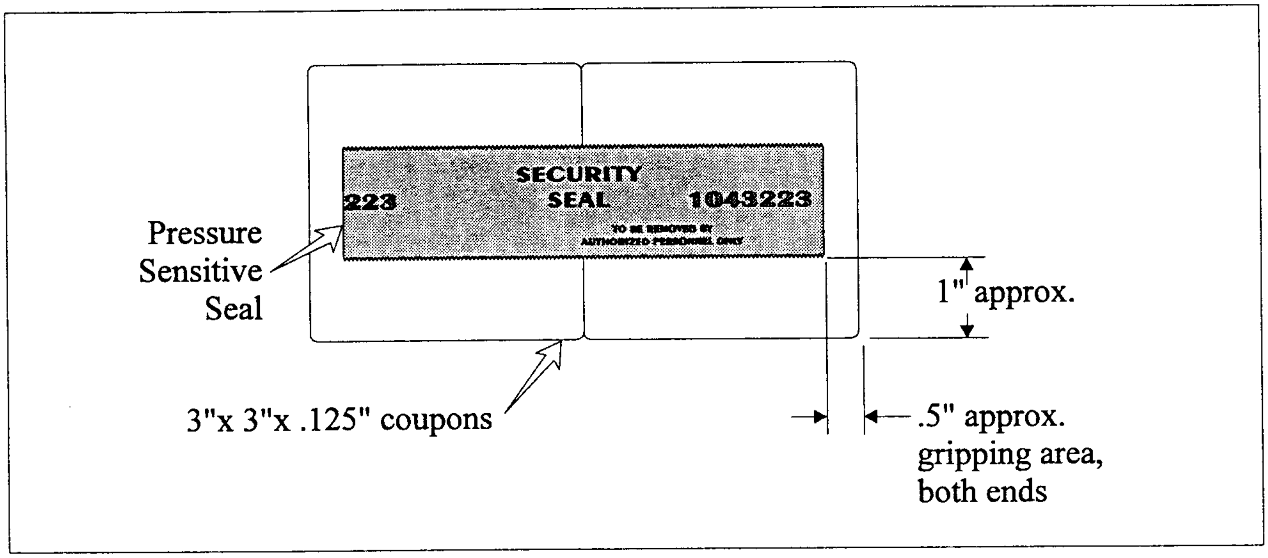


Figure 7. Shear Test Configuration

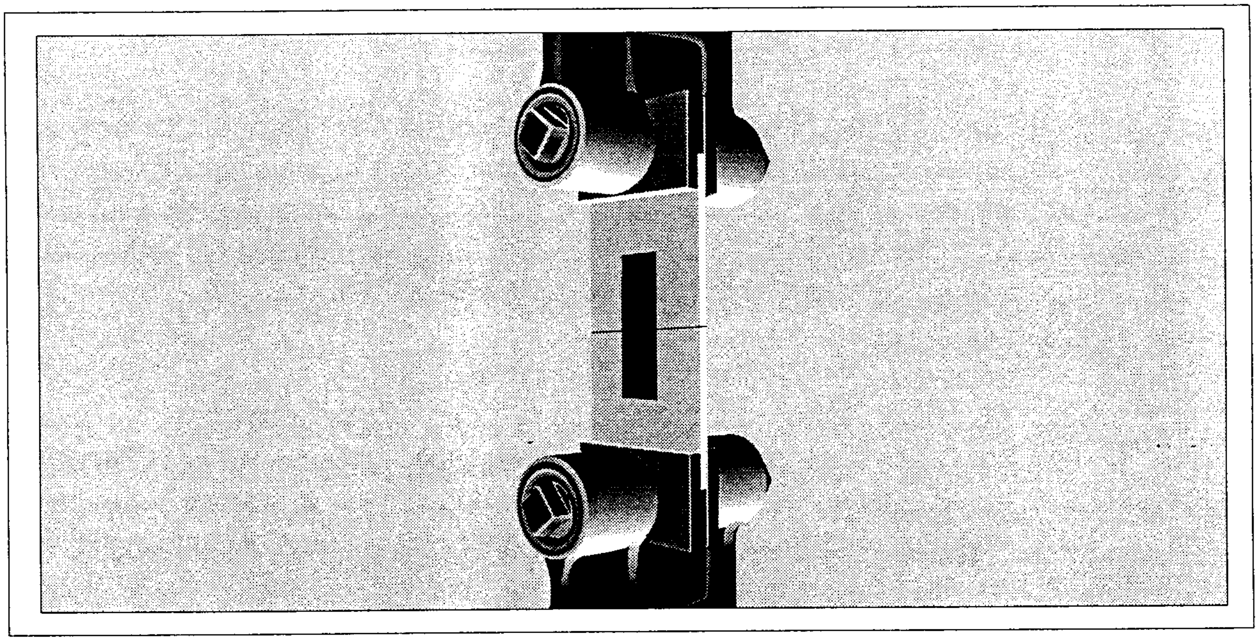


Figure 8. Shear Test Setup

Table 4. Shear Test Results

Pressure-Sensitive Seals	Substrate (coupon)	Environ-mental Factors	Average Point of Failure in Pounds	Comments
3M Confirm (12.3) [3]	painted surface	control	13	note 1
		radiation	14	note 1
	polyethylene	control	12	note 1
		radiation	10	note 1
	stainless steel	control	13	note 1
		radiation	12	note 1
ABN Holographic (50.3) [3]	painted surface	control	48	note 1
		radiation	52	note 1
	polyethylene	control	51	note 1
		radiation	49	note 1
	stainless steel	control	50	note 1
		radiation	52	note 1
TEMTEC Security Seal (21.83) [3]	painted surface	control	23	note 1
		radiation	22	note 1
	polyethylene	control	23	note 1
		radiation	22	note 1
	stainless steel	control	18	note 1
		radiation	23	note 1
Tyden WatchWord (99.3) [3]	painted surface	control	113	note 2
		radiation	110	note 2
	polyethylene	control	75	note 2
		radiation	92	note 2
	stainless steel	control	106	note 2
		radiation	100	note 2

note:

1. Broke at coupons butted joint.
2. Did not break but yeilded and necked down at butted joint then slipped along the substrate. In the stretchout area of the seal (the middle third), the individual letters of the word "open" were detectable.
3. Average point of failure for all tests in pounds.

4.3 Solvent Test. The adhesive and integrity-retention ability of the pressure-sensitive seal was tested after it had been subjected to several different solvents of varying levels of aggressiveness. The test results in Tables 5 through 8 reflect an average of the solvent effects. Since the solvents also affected the enamel-coated coupons, a row has been added to the bottom of each stage section in Table 5 to provide a comparison.

4.3.1 Test Description. In the solvent group, four separate manufacturer's seals (.75 x 2.75 inches) were adhered to a coupon's surface. They were evenly distributed across that coupon's surface (Figure 9), ensuring that even gaps were left between the seals and the coupon's edges. This was done for each of the three material groups of coupons.

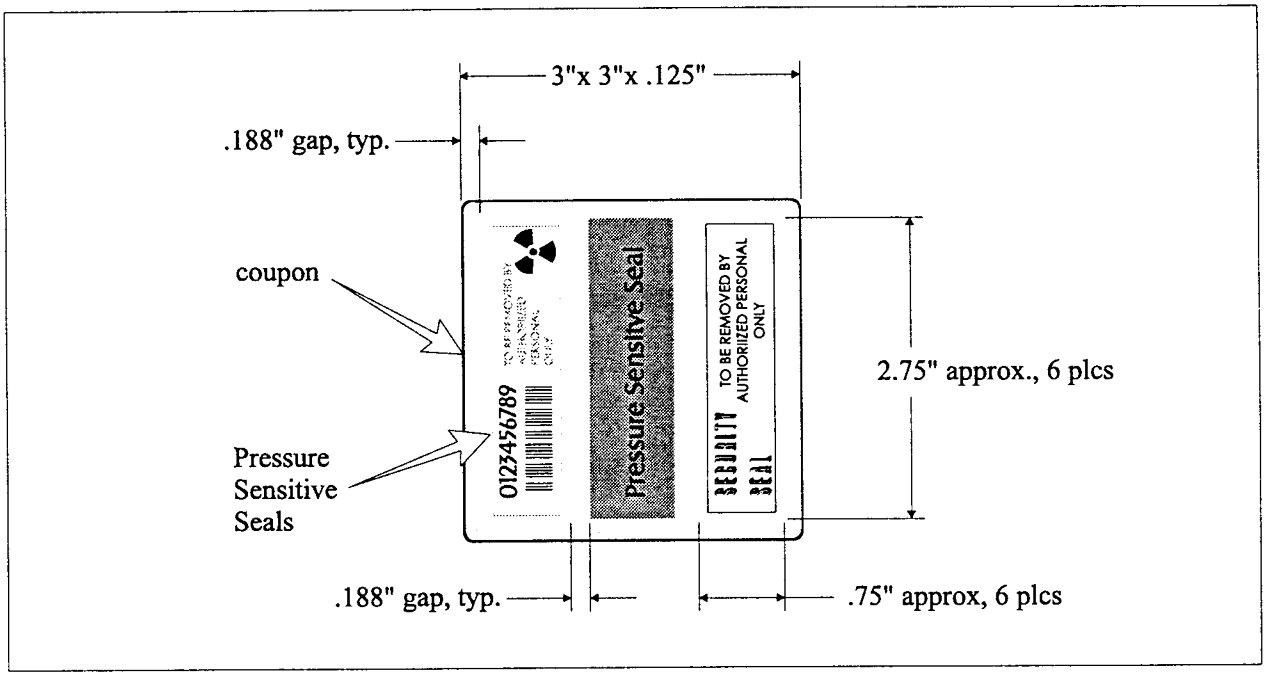


Figure 9. Solvent Test Configuration

4.3.2 Solvents. The nine solvents used, in order of aggressiveness, are shown below:

1. acetone
2. ethyl acetate
3. ethylene dichloride
4. heptane
5. turpentine
6. kerosene
7. methyl alcohol
8. Alconox® (detergent solution)
9. distilled or ionized water

4.3.3 Progressive Soaks. The solvent test was divided into three progressive soaks: One minute, two minute, and a second two minute for a total of five minutes of exposure to the solvent. After each soak, the seals were removed from the solvent. An attempt was then made to slide the seal from the coupon. A visual inspection was made and the results were noted.

4.3.4 Test Results. All solvent testing was done at room temperature. Of the three coupon surfaces tested, the polyethylene surface proved to be the most difficult surface to adhere to while under solvent attack. The enamel-painted surface proved a much better surface for adhesion than the polyethylene surface, and the stainless-steel surface proved to be the best surface for adhesion. While aggressive solvents attack a seal on a polyethylene surface more readily than they attack stainless steel and enamel, we still noted that if the seal failed the soak tests on one surface, it failed the tests on the other surfaces as well. A general overview of the mylar, vinyl, and acetate seals is given below in reference to the solvent tests.

4.3.4.1 Mylar Seals. The mylar seals (Tables 6 and 8) are durable against solvent attack because of their non-permeable, outer clear coat. In test results, the mylar seals showed no mechanical damage (i.e., no wrinkling or cracking that is typical of the vinyl seals) to the outer clear coat after a total soak time of five minutes. However, they did show some minor visual damage around the edges to the delicate substrate (the logo and serial number-embossed color coat) that is bonded with the adhesive coat. This damage was more pronounced with the polyethylene than it was with the stainless steel.

The mylar clear coat used by ABN could not withstand the aggressive solvents and the color coat (hologram) under the clear coat was visually blocked 100% by the milky appearance of the clear coat during the first-minute soak. This is an effective way to deter chemical attack on the clear coat due to the visual aspects of the reaction to the aggressive solvents.

The Tyden company prints their seal's logo, WatchWord, and a serial number on a satin finish, imprintable coating on top of the clear coat. The color coat has the company logo printed on it. The imprintable coating was sensitive to the aggressive solvents and would dissolve or deteriorate the printing along with the imprintable coating. The more aggressive solvents attack the acrylic adhesive along the perimeter and would distort the color coat in the process. This is very obvious visually and makes tampering with solvents difficult.

4.3.4.2 Vinyl Seals. The vinyl seal (Table 5) turned rubbery after soaking about three minutes in aggressive solvents. The vinyl seal was permeable to liquids, which allowed the aggressive solvents to attack the adhesive over the entire surface area of the seal. This caused the adhesive bond to fail and allowed the seal to slightly wrinkle while the vinyl transformed into a rubbery state. The outer coat of these seals, (alkyd polyester) is a very thin, translucent, onionskin-type coating. The onionskin is very delicate and the vinyl is approximately four times as thick as the vinyl seals tested in Volume I. The vinyl has a U-shape configuration and onionskin covers the entire rectangular shape. This configuration seems to offer more durability than the vinyl and paper seals. Yet, it offers an area of delicacy in the void area of the U-shape. This makes solvent tampering very difficult, especially in light of the onionskins' vulnerabilities to solvents.

4.3.4.3 <u>Acetate Seals</u>. The acetate seal (Table 7) dissolved after soaking approximately three minutes in aggressive solvents. This reaction is very visual and makes it difficult for solvent tampering to go undetected. Methyl alcohol attacks the acetate seal, but has less effect on the adhesive than does ethylene dichloride, ethyl acetate, and acetone.

Table 5. 3M Solvent Test Results

3M-Vinyl										
Three-Stage Soak ⇩	Solvents ⇨	Acetone	Ethyl acetate	Ethylene dichloride	Heptane	Turpintine	Kerosene	Methyl alcohol	Alconox	Water
STAGE 1	print /logo	note[1]	note[3] 100%	note[3] 50%	note[1]	note[1]	note[1]	note[1]	note[1]	note[1]
	serial number	note[1]	note[3] 100%	note[3] 50%	note[1]	note[1]	note[1]	note[1]	note[1]	note[1]
One-Minute Soak	alkyd polyester outercoat	note[3] 5% note[5]	note[3] 100%	note[7]	note[1]	note[1]	note[1]	note[1]	note[1]	note[1]
	vinyl coat	note[1]	note[1]	note[1]	note[1]	note[1]	note[1]	note[1]	note[1]	note[1]
	adhesive	note[1]	note[1]	note[1]	note[1]	note[1]	note[1]	note[1]	note[1]	note[1]
	*enamel on coupon	note[1]	note[1]	note[3] 25%	note[1]	note[1]	note[1]	note[1]	note[1]	note[1]
STAGE 2	print /logo	note[1]		note[3] 100%	note[1]	note[1]	note[1]	note[1]	note[1]	note[1]
	serial number	note[1]		note[3] 100%	note[1]	note[1]	note[1]	note[1]	note[1]	note[1]
Two Minute Soak	alkyd polyester outercoat	note[3] 25% note[6]		note[3] 100%	note[1]	note[1]	note[1]	note[1]	note[1]	note[1]
	vinyl coat	note[1]	note[3] 50%							
	adhesive	note[1]	note[3] 100%	note[1]	note[1]	note[1]	note[1]	note[1]	note[1]	note[1]
	*enamel on coupon	note[1]	note[1]	note[3] 40%	note[1]	note[1]	note[1]	note[1]		
STAGE 3	print/logo	note[1]			note[1]	note[1]	note[1]	note[1]	note[1]	note[1]
	serial number	note[6]			note[1]	note[1]	note[1]	note[1]	note[1]	note[1]
Two Minute Soak	alkyd polyester outercoat	note[3] 35% note[7]			note[1]	note[1]	note[1]	note[1]	note[1]	note[1]
	vinyl coat			note[3] 25%						
	adhesive	note[8]		note[3] 25%						
	*enamel on coupon	note[7]	note[3] 10%	note[3] 65%	note[1]	note[1]	note[1]	note[1]		

note:

1. No change after soak.
2. Not applicable.
3. Percentage damage (seal material or enamel) or faded (serial and print/logo). After soak: 100% indicates that seal failed test.
4. Outer coat (alkyd polyester / onion skin) slightly deforms at touch.
5. Outer coat is slightly milky. If it rubs off with light finger pressure, it fails the test.
6. Smears at the touch where the outer coat has begun to dissolve and thus fails the test.
7. Paint wrinkling under the seal begins to slide off the coupon with slight finger pressure. The vinyl is somewhat in tact. Polyester and stainless steel coupons fail the test.
8. Adhesive is beginning to fail. The seal is sliding off the coupon with slight finger pressure.

* The rest of the table refers to polyethylene, stainless, and enamel. Here, we refer only to enamel. (See section 4.3, Solvent Test.)

Table 6. ABN Solvent Test Results

ABN Mylar										
Three-Stage Soak ⇩	Solvents ⇨	Acetone	Ethyl acetate	Ethylene dichloride	Heptane	Turpintine	Kerosene	Methyl alcohol	Alconox	Water
STAGE 1	hologram	note [3] 100%	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]
One Minute Soak	clear mylar outer coat	note [3] 100% note [4]	note [3] 100%	note [3] 100%	note [3] 100%	note [1]	note [1]	note [1]	note [1]	note [1]
	colorMylar under coat	note [1] note [1]	note [1]	note [1]						
	adhesive	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]
STAGE 2	hologram	note [1]	note [1]	note [3] 75%	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]
Two Minute Soak	clearMylar outer coat	note [1]	note [3] 50%		note [1]	note [1]	note [1]	note [1]	note [1]	note [1]
	colorMylar under coat	note [3] note [1]	note [3] 10%	note [3] 25% note [7]						
	adhesive	note [1]	note [3] 10%	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]
STAGE 3	hologram	note [1]	note [1]		note [1]	note [1]	note [1]	note [1]	note [1]	note [1]
Two Minute Soak	clearMylar outer coat	note [5]	note [3] 100%		note [1]	note [1]	note [1]	note [1]	note [1]	note [1]
	colorMylar under coat	note [1]	note [1]	note [3] 50%						
	adhesive	note [1]	note [1]	note [3] 50%	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]

note:

1. No change after soak.
2. Not applicable.
3. Percentage damage (seal material or enamel) or faded (serial and print/logo). After soak: 100% indicates that seal failed test.
4. Milky glazed and rough textured.
5. Smears at the touch where it has begun to dissolve.
6. Paint damaged (wrinkled) around the seal. Paint under the seal is unaffected.
7. Colored mylar undercoat damaged when rubbed.

Table 7. TEMTEC Solvent Test Results

		TEMTEC Acetate								
Three-Stage Soak ⇩	Solvents ⇨	Acetone	Ethyl acetate	Ethylene dichloride	Heptane	Turpintine	Kerosene	Methyl alcohol	Alconox	Water
STAGE 1	print	note [3] 100%	note [3] 100%	note [1]	note [1]	note [1]	note [1]	note [3] 100%	note [1]	note [1]
	flexographic ink outer coat	note [3] 100% note [4]	note [3] 100% note [5]	note [1]	note [1]	note [1]	note [1]	note [3] 100%	note [1]	note [1]
One Minute Soak	acetate under coat	note [3] 100% note [4]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]
	adhesive	?	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]
STAGE 2	print			note [1]	note [1]	note [1]	note [1]		note [1]	note [1]
	flexographic ink outer coat			note [1]	note [1]	note [1]	note [1]		note [1]	note [1]
Two Minute Soak	acetate under coat		note [3] 75% note [5]	note [6]				note [4]		
	adhesive		note [3] 75%	note [3] 25% note [6]	note [1]	note [1]	note [1]	?	note [1]	note [1]
STAGE 3	print			note [1]	note [1]	note [1]	note [1]		note [1]	note [1]
	flexographic ink outer coat			note [1]	note [1]	note [1]	note [1]		note [1]	note [1]
Two Minute Soak	acetate under coat			note [6]						
	adhesive			note [3] 65% note [6]	note [1]	note [1]	note [1]		note [1]	note [1]

note:

1. No change after soak.
2. Not applicable.
3. Percentage damage (seal material or enamel) or faded (serial and print/logo). After soak: 100% indicates that seal failed test.
4. Turns to pink gel and fails test.
5. Smears at the touch where it has begun to dissolve.
6. Curling up at the edges where adhesive failure is occuring.

Table 8. Tyden Solvent Test Results

Tyden Mylar										
Three-Stage Soak ⇩	Solvents ⇨	Acetone	Ethyl acetate	Ethylene dichloride	Heptane	Turpintine	Kerosene	Methyl alcohol	Alconox	Water
STAGE 1 One Minute Soak	print (serial #)	note [3]	note [3] 100%	note [3] 100%	note [1]	note [3] 75% note [4]	note [1]	note [1]	note [1]	note [1]
	logo	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]
	imprintable coating	note [1]	note [3] 100%	note [3] 100%	note [1]	note [3] 75%	note [1]	100%	note [1]	note [1]
	clearMylar outer coat	note [1]	note [1]	note [1]	note [1]	note [3] 75%	note [1]	note [1]	note [1]	note [1]
	colorMylar under coat	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]
	adhesive	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]
STAGE 2 Two Minute Soak	print (serial #)	note [1]			note [1]	note [3] 100%	note [1]	note [1]	note [1]	note [1]
	logo	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]
	imprintable coating	note [1]	note [3] 100%	note [3] 100%	note [1]	note [3] 100%	note [1]	note [1]	note [1]	note [1]
	clearMylar outer coat	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]
	colorMylar under coat	note [1]	note [3] 10% edges	note [1]	note [1]	note [1]	note [1]		note [1]	note [1]
	adhesive	note [1]	note [3] 10%	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]
STAGE 3 Two Minute Soak	print (serial #)	note [1]				note [1]	note [1]	note [1]	note [1]	note [1]
	logo	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]
	imprintable coating	note [1]				note [1]	note [1]	note [1]	note [1]	note [1]
	clearMylar outer coat	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]
	colorMylar under coat	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]
	adhesive	note [1]	note [1]	note [3] 25%	note [1]	note [1]	note [1]	note [1]	note [1]	note [1]

note:

1. No change after soak.
2. Not applicable.
3. Percentage damage (seal material or enamel) or faded (serial and print/logo). After soak: 100% indicates that seal failed test.
4. Smears at the touch where it has begun to dissolve.
5. Paint damaged (wrinkled) around the seal. Paint under the seal is unaffected.

5. Loop Seals

5.1 Cobra Seal, Aquila Technologies. The three loop seals identified in the introduction are further described in this section. Two fiber optic and one wire loop seal are discussed. The Cobra Seal (Figure 10) uses a fiber optic bundle with 64 strands of fibers shielded by a black PVC outer coat. The diameter of the bundle is .126 ± .002 inches. A modified Canon RC-250 Xapshot™ camera attaches to the end of the seal body to capture the fiber optic loop-end bundle image along with the embossed serial number. This camera has been superceded by a digital system called Auto Cobra.

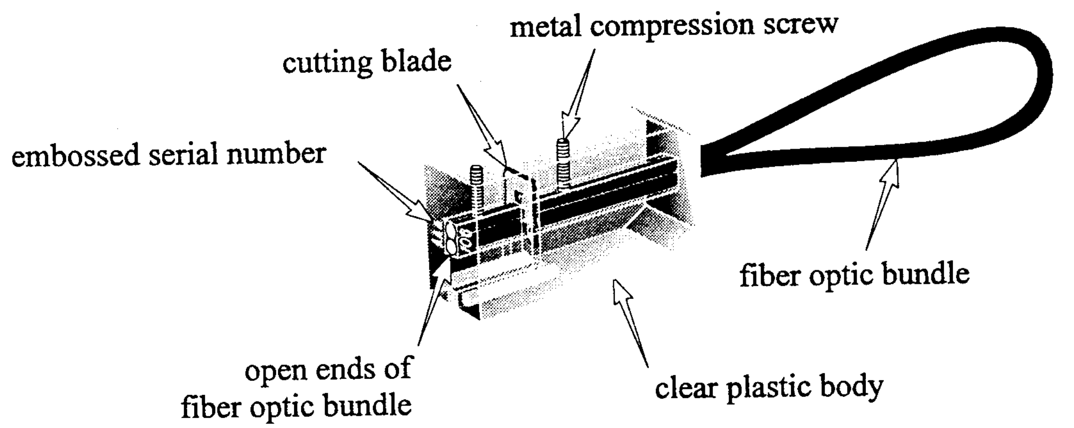


Figure 10. Cobra Seal Configuration

5.2 Fiber-Lock Seal, E. J. Brooks. The Fiber-Lock seal (Figure 11) uses a fiber optic bundle with 16 strands of fibers shielded by a black polyethylene outer coat. The diameter of the bundle is .087 ± .002 inches. A modified Polaroid™ camera attaches to the end of the seal body. The camera captures the fiber optic open-end bundle image along with the heat-stamped serial number.

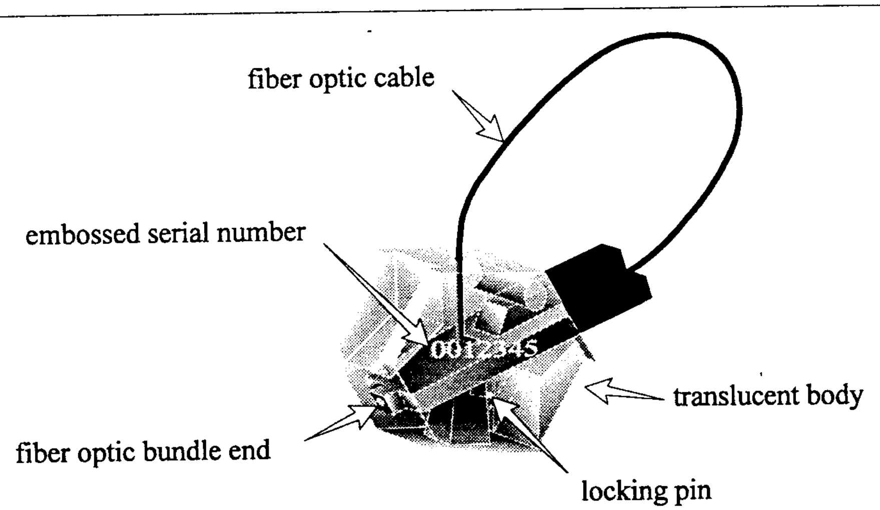


Figure 11. Fiber-Lock Seal Configuration

5.3 Multi-Lok Seal (DOE #8909412), E. J. Brooks. The Multi-Lok seal (Figure 12) consists of a 1/16 inch diameter braided-steel cable with a standard length of 12 inches. The cable tensile strength is just under 1,000 pounds. The loop seal cable is threaded through a hasp or other orifice then through the hole at the top of the locking body. As the cable passes through the main body, it slightly compresses the locking spring and allows the cable to exit from the bottom of the seal. The cable is then cinched up tightly.

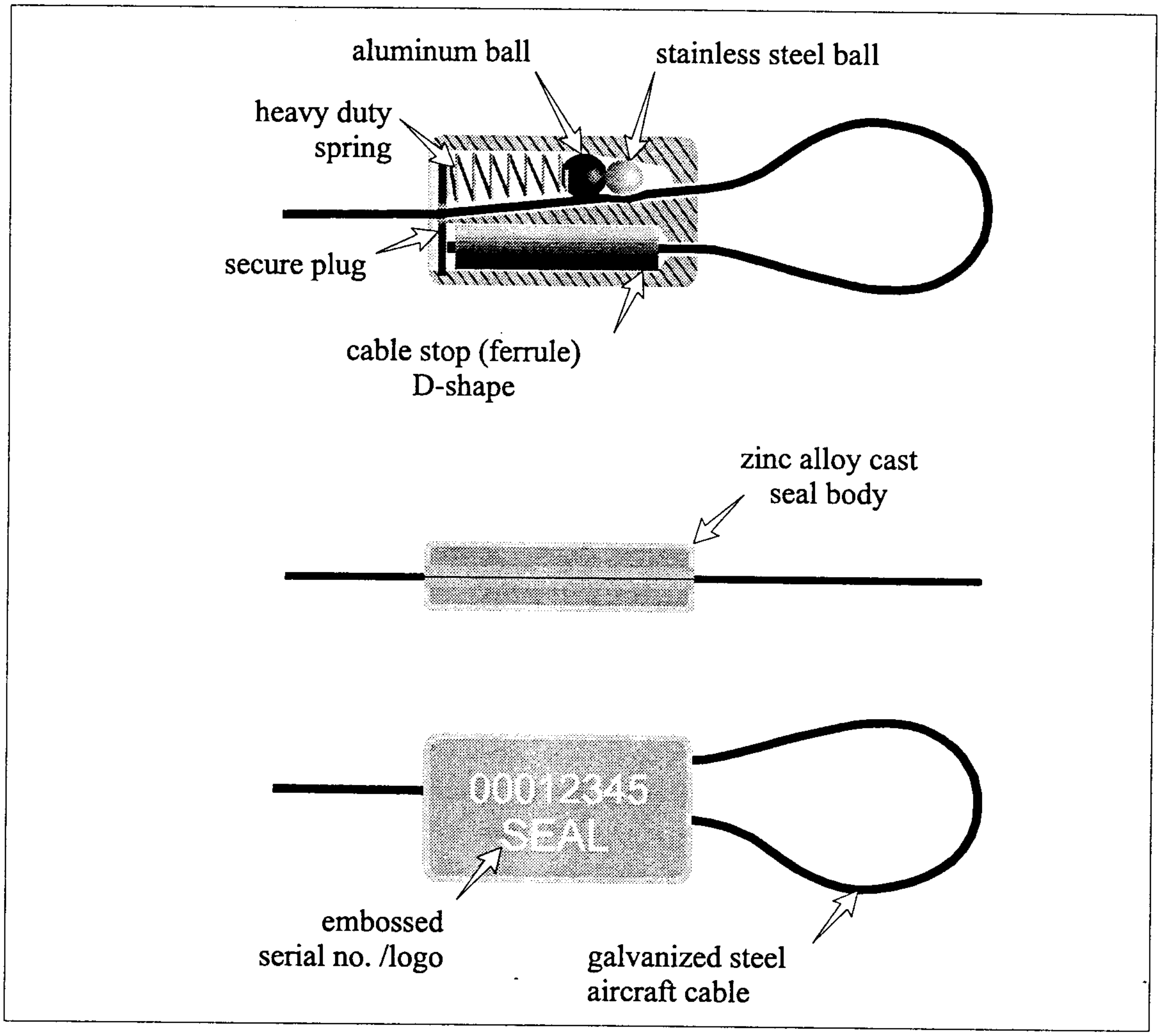


Figure 12. Multi-Lok Seal Configuration

6. Loop Seals Testing

Loop seal testing consists of subjecting the seals to drop and pull tests, a 20-day high temperature / high humidity test, a vibration test, and a radiation test.

6.1 Mechanical Drop and Pull Test. The mechanical drop and pull tests measure the ability of the loop seal to withstand physical stresses of the type likely to be encountered in normal handling.

6.1.1 Test Description. A control group, a 20-day environmental group, and a radiation group of the Cobra and Fiber-Lock loop seals were subjected to the drop and pull test. Due to the late arrival of the Multi-Lok during testing, only the control group for this seal was tested. Test equipment consisted of:

- A 12 inch long nylon cord (1/8 inch diameter, minimum 75-pound test)
- A five-pound weight
- A fifty-pound weight
- A four-screw hasp wall mount (1/8 inch diameter, U-shaped with minimum 3/16 inch modified opening).

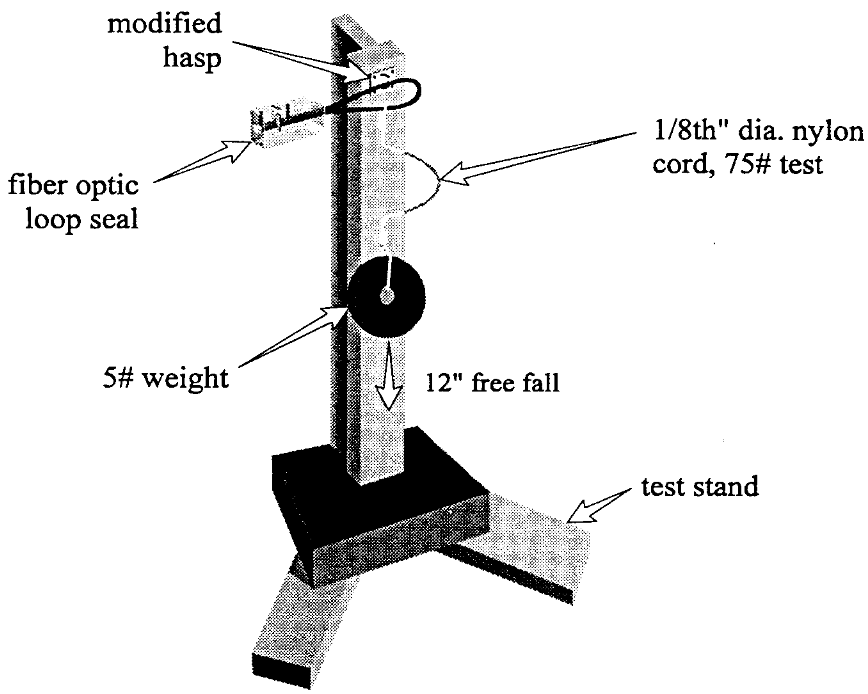


Figure 13. Loop Seal Drop Test

6.1.2 Drop Test Procedures. The loop seals were attached to a 12-inch long cord as shown in Figure 13. The seal's assembly loop was hooked onto the hasp which was secured to the face of a vertical fixture 24 inches above a horizontal surface. This test also served as a loop-bend test. The five-pound weight was attached to the opposite end of the cord and dropped for a free-fall of 12 inches.

6.1.3 Pull Test Procedures. The loop seals were attached to a 12-inch long cord as shown in Figure 14. The loop was hooked onto the hasp, which was secured to the face of a vertical fixture 24 inches above a horizontal surface. The loop seal was subjected to a constant 50-pound pull on the hasp for one minute.

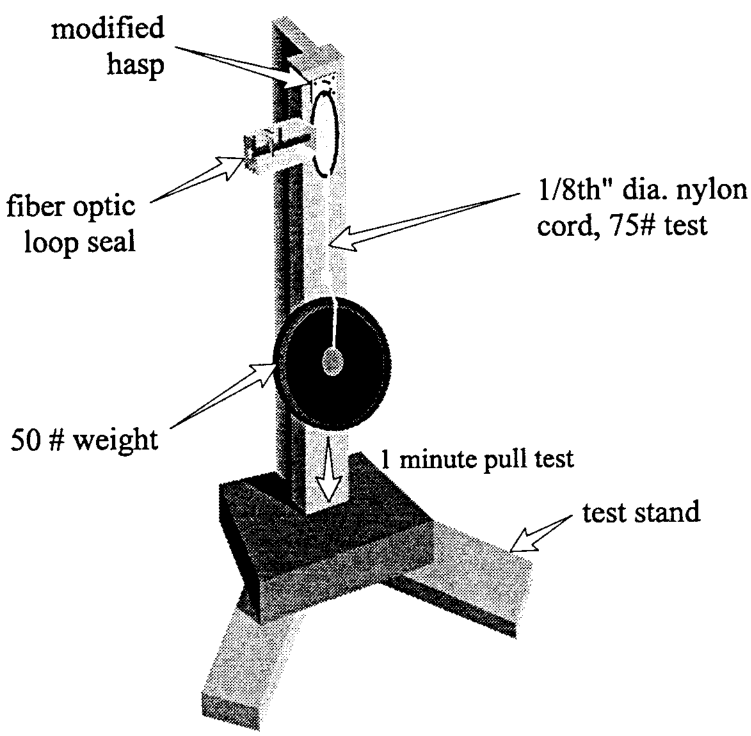
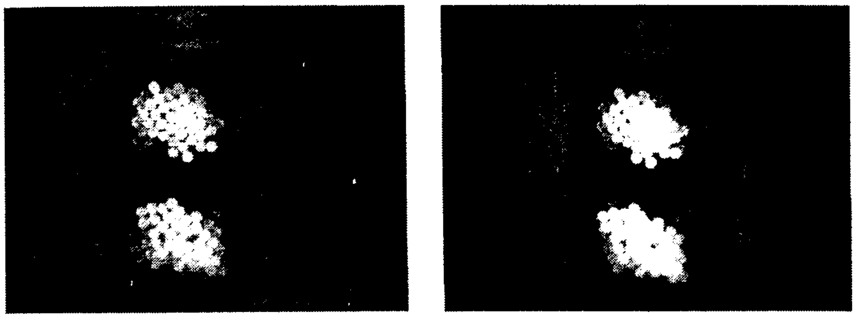


Figure 14. Loop Seal Pull Test

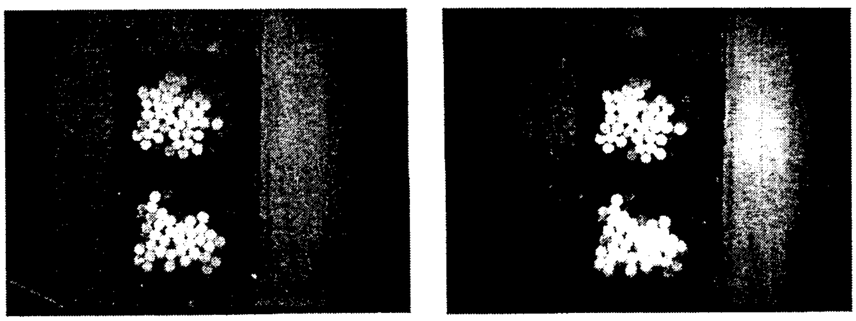
6.1.4 Test Results:

6.1.4.1 Cobra. The Cobra subassembly held up during the drop and pull tests. Both drop and pull tests changed the normal teardrop loop shape to an elliptical shape with radiused ends left from the hasp and the 12 x .125 inch diameter cord. All three test groups passed the test. Figures 15 and 16 show the before and after photos of the fiber bundle ends of the pull and drop testing of the control group. The bundles show no change in their light / dark fibers or in fiber orientation.



Before After

Figure 15. Cobra Seal Fiber Optic Bundle (Photos from Pull Test)



Before After

Figure 16. Cobra Seal Fiber Optic Bundle (Photos from Drop Test)

6.1.4.2 Fiber Lock. The Fiber Lock seal failed the drop and pull tests because the fiber broke. After the Fiber Lock's loops failed, the E. J. Brooks Company was contacted. They have recognized the failure mode and furnished a through hole for cable-tie support of the fiber optic loop. SNL was assured this version had been tested with a cable tie installed to determine pull strength.

6.1.4.3 Multi-Lok. The Multi-Lok seal passed the drop and pull tests with no adverse effects. The drop and pull tests changed the normal teardrop loop shape to an elliptical shape with radiused ends left from the hasp and the 12 inch cord. This is typical of loop seal cables and fiber optic loops that passed the test.

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7. General Testing

7.1 Vibration Test. The vibration test subjects the seals to physical stresses that can be expected under normal handling and transporting conditions.

7.1.1 Test Description. Vibration testing was conducted using:

- a modified 30-gallon drum with locking collar and lid (secured to a longitudinal axis or a transverse axis vibration unit),
- a one-gallon paint can,
- typical packing material.

We used MIL-STD-810D Figures 514.3-1, 514.3-2, and 514.3-3 from the section on basic transportation and the common carrier environment as guides for vibration testing. All testing was done on a control group only. The tests were conducted at 40°F and 95°F.

7.1.2 Test Procedures. Figure 17 shows the following assembly procedure:

- The disks were placed in the bottom of the drum.
- The washer-shaped rings were then put into the drum to a height of the paint can.
- The paint cans were then filled with fine sand and sealed; they were then placed inside the Celetex rings. The pressure-sensitive seals overlapped the lids and sides of the paint cans.
- The stays were fit snugly into the gap between the paint can and the rings. In four places, the stays were positioned against two sets of seals that were placed 90 degrees apart outside the can.
- A thermocouple lead was metal taped to the top of the paint can. (In this position, it records temperatures during vibration testing.)
- A spacer ring (not shown in Figure 17) was placed into the void of the top ring which is located on top of the paint can.
- Two more disks were placed on top of the rings and the paint-can assembly.
- The drum lid was then put into place and secured by the drum's locking collar.
- Cobra and Fiber-Lock loop seals were alternately secured through the two holes in the drum collar bolt.
- The bottom of the modified drum had 2 x 1/8 inch steel tubing welded to the inner walls of the drum. One leg of this mount extended outside of the drum so that the load cell could be attached.
- Prior to placing the assembly into the modified drum, the assembly was bolted onto the vibration unit through bolt holes in the mount tubing.

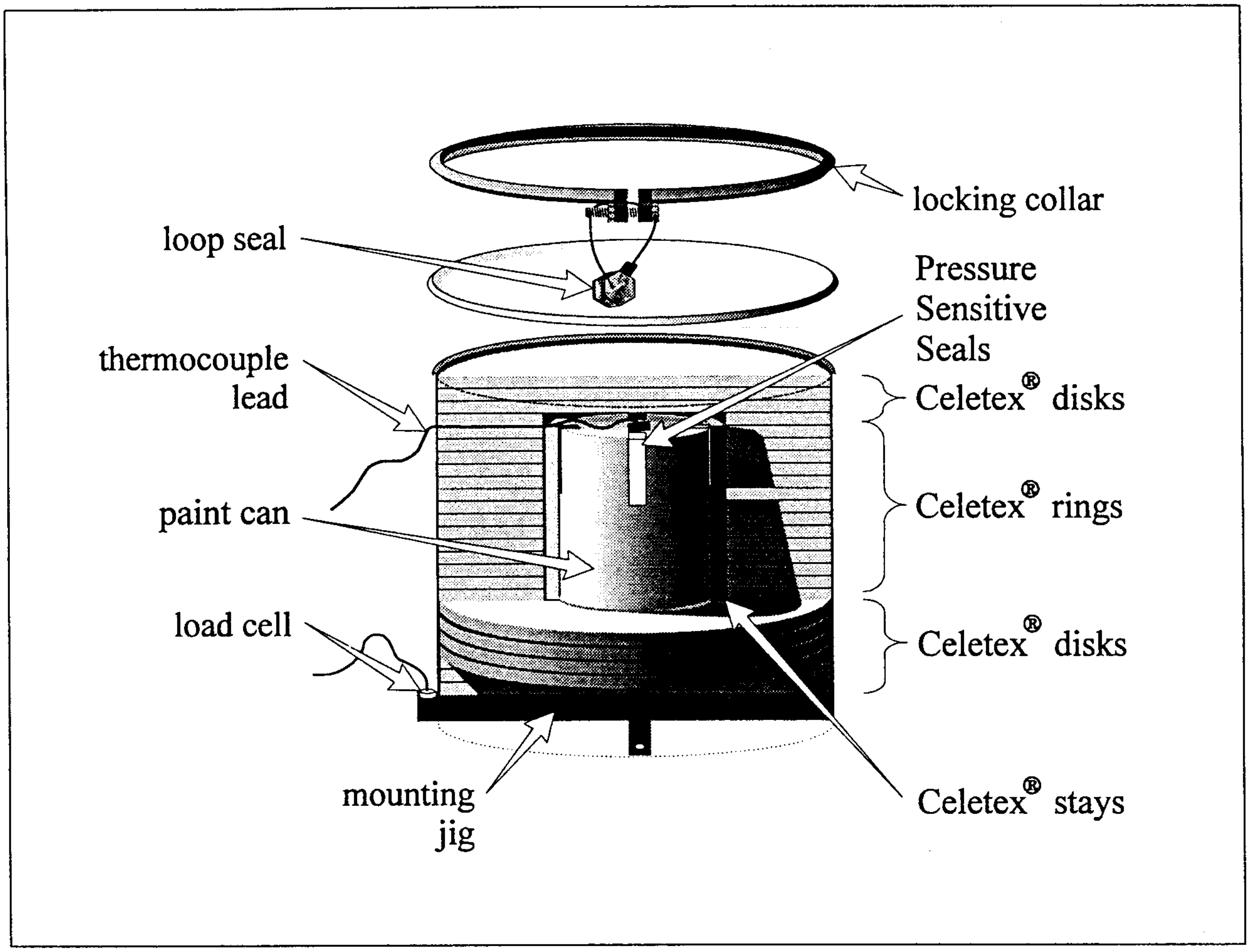


Figure 17. Vibration Test Setup

7.1.3 Test Results. All pressure-sensitive seals and loop seals passed the vibration testing. There was minor abrasion wear on the vinyl and acetate pressure-sensitive seals. The snug fit installation of the stays was more responsible for this partial rubbing off of the logos than was the vibration testing itself.

7.2 Drop Test. Handling durability of the seals is tested by physical stresses that can be expected under normal moving and transporting conditions.

7.2.1 Test Description. There were two parts to the drop test. One test consisted of a 30-gallon drum assembly, like the vibration test (drum not modified) with the same disk, rings, and paint-can assembly. This test (Figure 18) was a 30 inch drop test. The second test utilized the paint can alone (Figure 19) in a 30 inch drop-shock. This testing was conducted on a control group only.

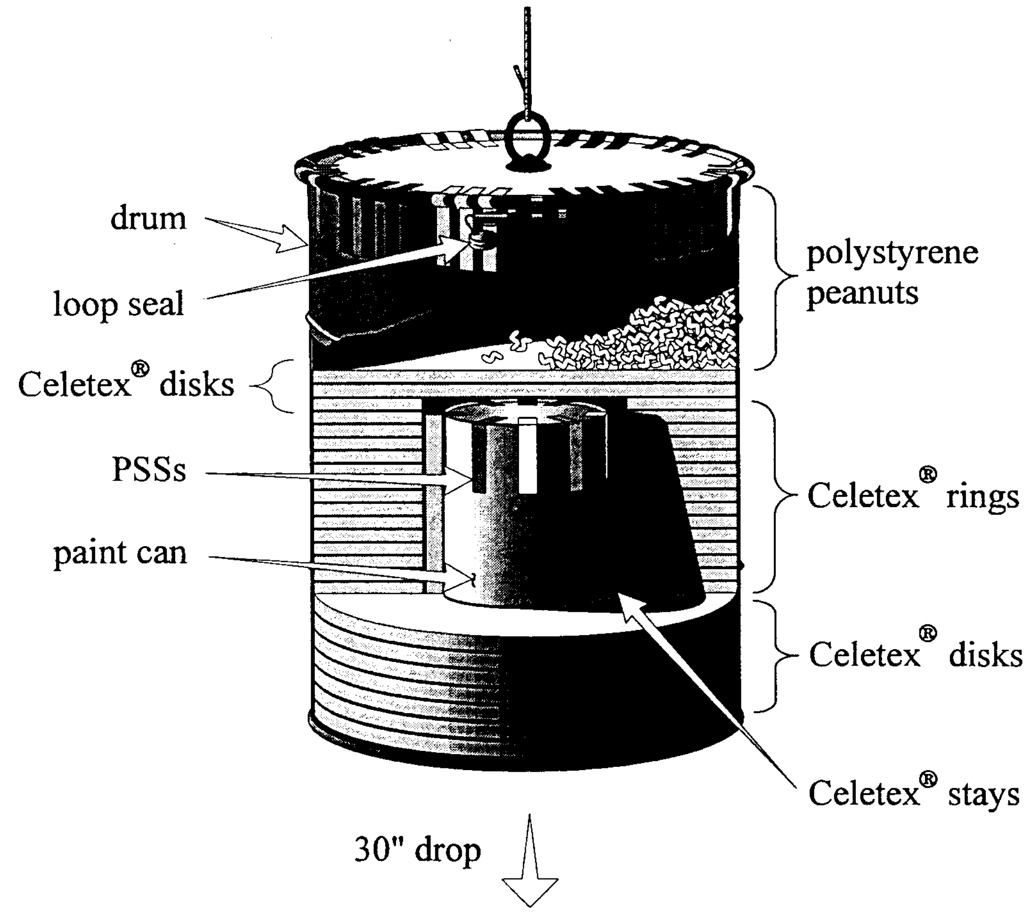


Figure 18. Shock Test Setup

7.2.2 <u>Test Procedures</u>: *Thirty Gallon Test.* In the drum assembly drop test, the pressure-sensitive seals were not only located on the paint can, but were also located on the outside of the 30-gallon drum. The pressure-sensitive seals were placed in groups of threes (three of each manufacturers' seals) going from the lids around the locking collar and down the sides. The loop seals were placed on the locking collar bolt. The assembly, weighing 87 pounds., was secured to an overhead hoist with 100 pound test 1/8 inch diameter nylon cord. The cord was attached to an eyebolt that had been bolted through the center of the drum lid. The cord was cut and the drum dropped 30 inches onto a concrete surface.

One Gallon Test. The paint can drop test (Figure 19) assembly weighed 15.6 pounds. The assembly was secured to an overhead hoist with 100 pound test 1/8 inch diameter nylon cord. The cord was cut and the paint can dropped 30 inches onto a concrete surface.

7.2.3 <u>Test Results</u>. The paint can seals suffered no visible damage in both tests. However, the pressure-sensitive seals on the outside of the drum all showed some damage. The vinyl seals seemed to have the same type damage; they showed stress cracks between the collar and the vertical walls of the drum. These cracks were usually parallel to the locking collar and never ran more than 75% of the width of the seal. Most of the cracks would start on each side and be about 1/8 inch long. The mylar seals showed minor, if any, void print around the area of the locking collar on the sides of the lids and drums. This void usually was visible within the first 1/8 inch of adhesive contact from the gap of the collar on the surface of the lid and / or sides. Overall, the three pressure-sensitive seal types were affected in the same way as were the others within their material group. The loop seals showed no effect at all.

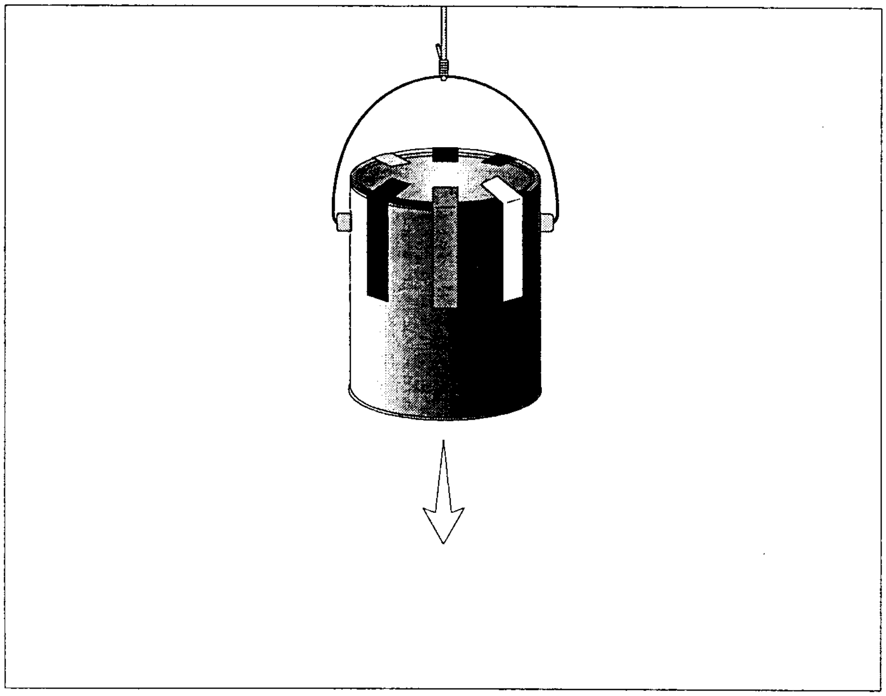


Figure 19. Drop-Shock Test Setup (Paint Can)

7.3 Abrasive Test. The abrasive test measures the durability of the seals under stress expected under normal handling and moving conditions.

7.3.1 Test Procedures. The abrasive test was performed on the pressure-sensitive seals using 400 grit sandpaper in 1 x 6 inch strips. The sandpaper was adhered to a 1 x 6 x 5 inch, 5.5 pound. rectangular flat steel plate. The plate was slid across the seals (Figure 20) three times. After each pass, the results were recorded. After each seal's abrasive test, the sandpaper was replaced.

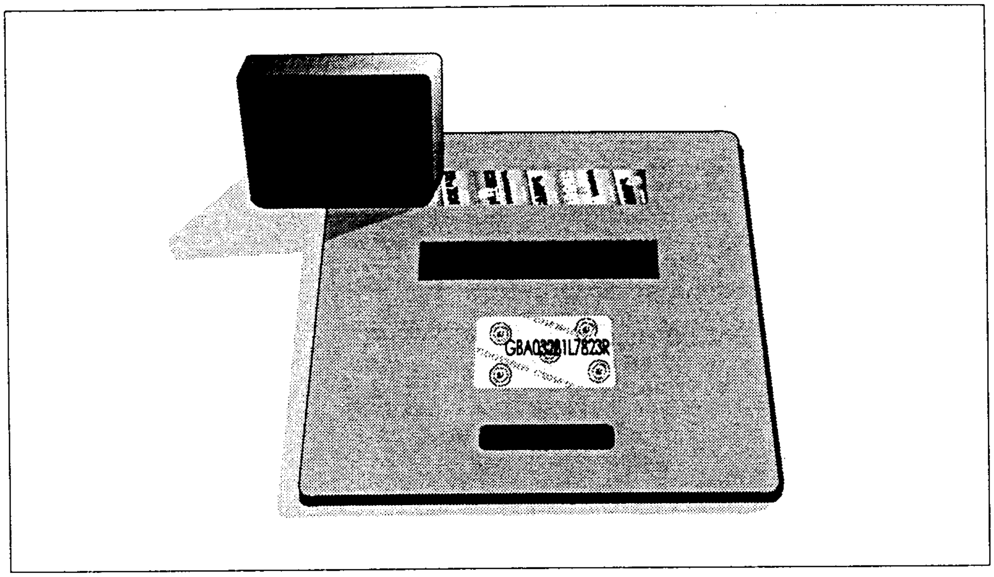


Figure 20. Abrasive Test Setup

7.3.2 <u>Test Results</u>:

- *3M*. The logos were not so adversely affected that the light viewer could not pick up the retroreflective image of Triskelions® and the printed serial numbers were undamaged.
- *ABN*. The test had no effect beyond scuffing the clear coat.
- *TEMTEC*. The outer imprintable dye coating with factory printing came off completely, leaving the clear acetate seal underbody visible in an intermittent pattern.
- *Tyden*. The satin finish imprintable coating, the seal logo "WatchWord", and a serial number were visually scuffed up, and the print of the logo and a serial number were partially (25%) removed.

7.4 <u>Humidity Test</u>:

7.4.1 <u>Test Procedures</u>:

7.4.1.1 <u>Pressure Sensitive Seals</u>. Three samples of each pressure-sensitive seal were placed in an environmental chamber. After a 20-day test, the seals were removed and inspected for deterioration of the serial number, the adhesive, and the material. A pressure-sensitive seal failed the test if a functional disability occurred due to adhesive or material failure, or if the serial number and printing / logos showed more than 25% damage.

7.4.1.2 <u>Loop Seals</u>. Three samples each were placed in an environmental chamber. After a 20-day test, the seals were removed and inspected for deterioration and corrosion. A loop seal failed the test if a functional disability occurred due to corrosion or deterioration.

A functional disability is defined as:

- a locking mechanism failure,
- rust or oxidation that causes loss of structural integrity, and / or
- a serial number that cannot be read.

7.4.2 Test Results. All pressure-sensitive seals passed the test with no visual effects of testing. The cobra and Fiber-Lock assemblies passed the 20-day humidity test with no visible damage to the two fiber optic bodies. The Multi-Lok loop seals were not a part of the testing at the time of the 20-day humidity test. Figures 21 and 22 show the before testing and after testing results on the fiber optic bundles of both loop seals with no visible damage or alteration to the bundle patterns.

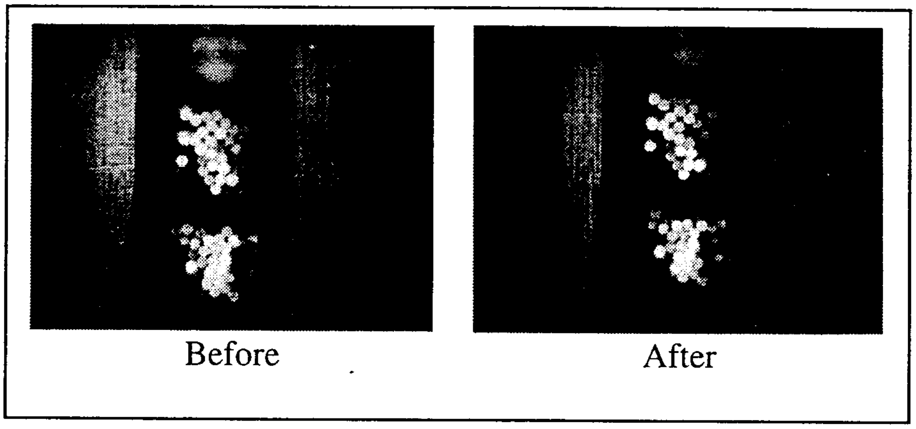


Figure 21. Cobra Seal Fiber Optic Bundle Photos (From 20-Day High Temperature / High Humidity Test)

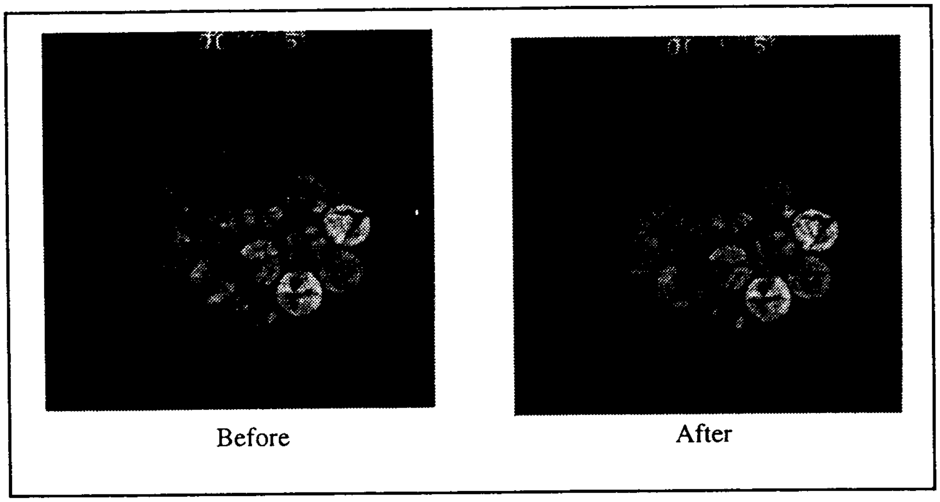


Figure 22. Fiber-Lock Fiber Optic Bundle Photos (From 20-Day High Temperature / High Humidity Test)

7.5 Radiation Test:

7.5.1 Test Procedures. This test was conducted by subjecting the seals to 1,000 R cumulative radiation exposure over a period of one hour and four minutes. Samples of the seals were placed in the Gamma Irradiation Facility (GIF) chamber. They were placed on an aluminum test stand array at a six-foot radius away from the Cobalt-60 source and three feet above floor level similar to that shown in Figure 23.

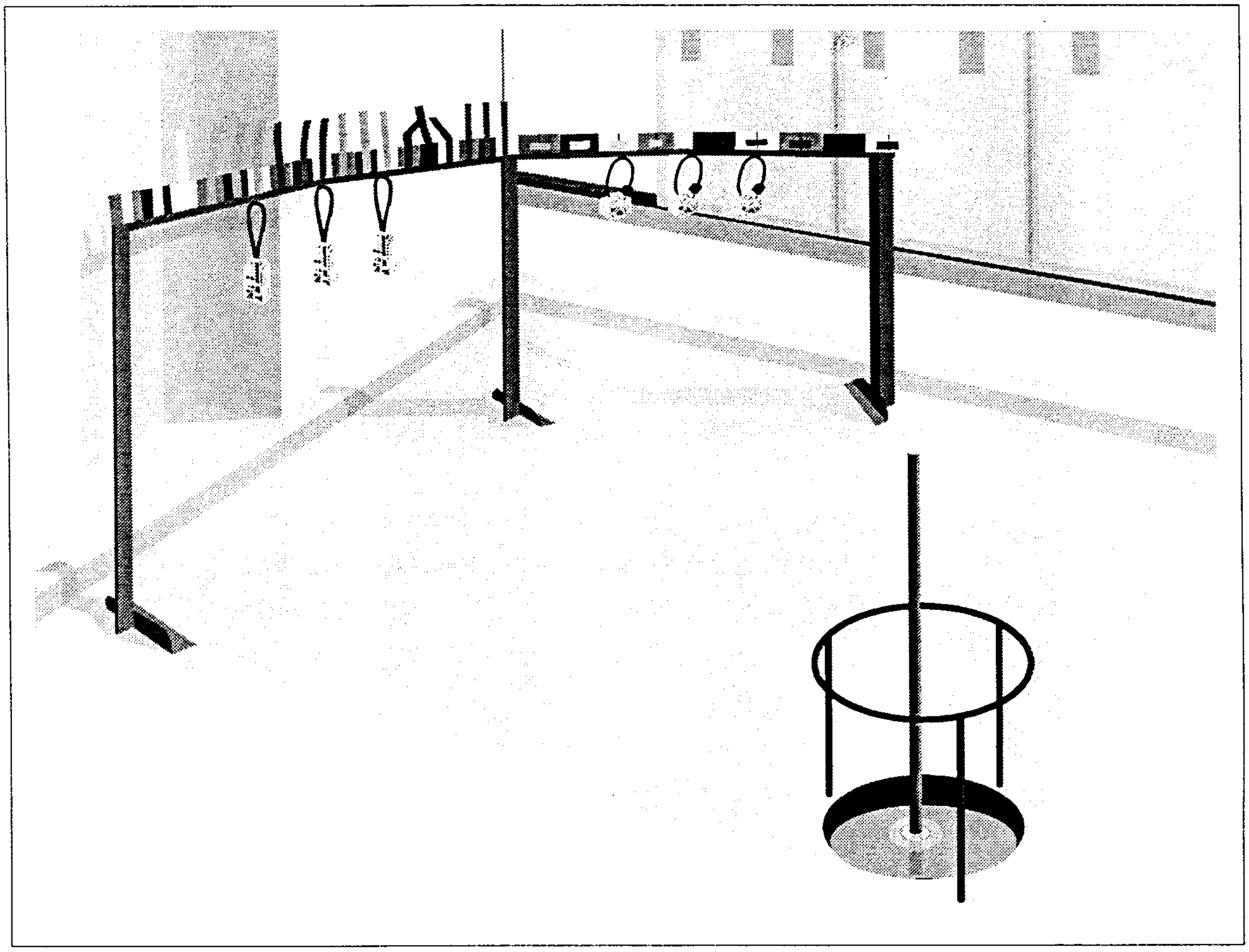


Figure 23. Radiation Test Layout

C

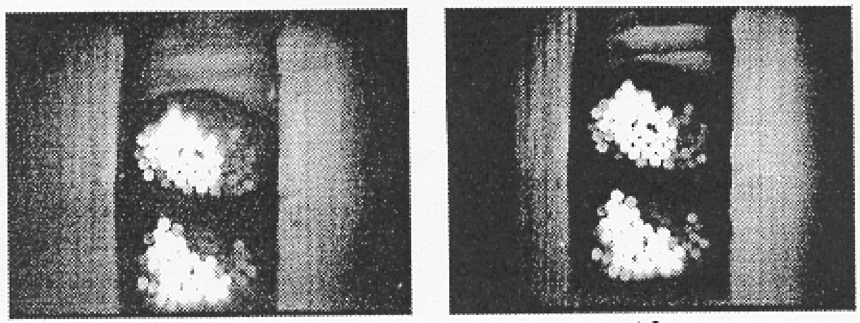
7.5.2 Pressure Sensitive Seals. The seals were placed on coupons for shear and peel testing. After exposure, the seals were removed and inspected for deterioration of the following:

- serial number,
- adhesive, and
- mylar, vinyl, and acetate materials.

A pressure-sensitive seal failed the test if a functional disability occurred due to adhesive or material failure, or if the serial number and printing / logos showed more than 25% damage.

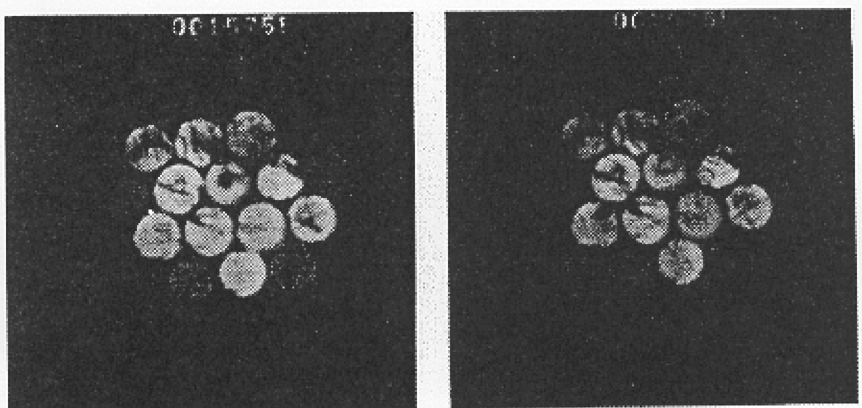
7.5.3 Loop Seals. After exposure time, the seals were removed; they were then visually examined for deterioration. A loop seal failed the test if a functional disability occurred.

7.5.4 Test Results. All seals passed the tests with no visable radiation effects.



Before After

Figure 24. Cobra Seal Fiber Optic Bundle Photos (From 1,000 R Radiation Test)



Before After

Figure 25. Fiber-Lock Fiber Optic Bundle Photos (From 1,000 R Radiation Test)

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8. Summary and Recommendations

8.1 Testing Summary. In this report, we compare loop and pressure-sensitive seals for durability and tamper resistance and evaluate two fiber optic loop seals. The seals we selected are intended for use at DOE facilities where they protect and monitor SNM. The seals should meet the following specifications:

- • reasonable cost,
- • resistance to environmental conditions,
- • verification of seal serial number and integrity,
- • ability to withstand handling,
- • ability to indicate any attempt to tamper with the device,
- • relative ease and speed of application, and
- • ability to fit and adhere to a variety of containers and their surface materials.

8.1.1 Pressure Sensitive Seals Testing Results:

The following ***pressure-sensitive seals*** *were tested:*

- • **3M** *Confirm* seal,
- • **ABN** *Holgraphic* seal,
- • **TEMTEC** *Security* seal, and
- • **Tyden** *WatchWord* seal.

8.1.1.1. Abrasive Test Results. The 3M and ABN seals were scuffed but readable. The TEMTEC and Tyden were badly marred.

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8.1.1.2. Radiation Test Results. All seals passed the test with no visual effects of the radiation testing. Mechanical testing after this test also revealed no sign of significant degradation due to radiation exposure..

8.1.1.3. Temperature / Humidity Test Results. All pressure-sensitive seals passed the test with no visual effects of testing.

8.1.1.4. Peel Test Results. The mylar seals averaged 1.02 pounds prior to failure. The vinyl seals averaged 1.25 pounds prior to failure.

8.1.1.5. Shear Test Results. The mylar seals averaged 74.80 pounds prior to failure. The vinyl seals averaged 17.08 pounds prior to failure.

8.1.1.6. Drop Test Results. In the 30-gallon test, some of the pressure-sensitive seal types demonstrated cracking but did not completely fail. All pressure-sensitive seals in the paint can drop test survived this test with no visible damage to them.

8.1.1.7. Solvent Test Results. The mylar seals are durable against solvent attack because of their nonpermeable, outer clear coats. The vinyl seals experienced varying degrees of solvent attack. The *TEMTEC* seal's print and outercoat were 100% damaged after soaking approximately one minute in the more aggressive solvents (acetone, ethyl acetate, and methyl alcohol). The *3M* seal's print / logo, serial number, and alkyd polyester outercoat were 100% damaged after soaking approximately one minute in the ethyl acetate. The print / logo and serial number were 50% damaged after soaking approximately one minute in the ethylene dichloride. The print / logo and serial number were 100% damaged after soaking three minutes during stage two in the ethylene dichloride. These reactions are very visual and make it difficult to do undetected solvent tampering.

Of the three coupon surfaces tested in the solvent test, polyethylene was the most difficult surface to adhere to while under solvent attack. The enamel-painted surface proved better, and the stainless-steel surface was the best surface for adhesion.

8.1.1.8. Vibration test results. The mylar and vinyl seals showed no mechanical damage. The vinyl seals showed some scuffing from the stays when they were slid into place prior to testing and on removal.

8.1.1.9. Summary. Table 9 shows the resultant ranking of the pressure sensitive seals tested by type with the number "1" representing the best rating in that particular category. There are some differences between different seals in each category but, in general, the primary difference is in the material. All of these seals could be defeated by the vulnerability analysts if they were allowed an unconstrained environment. However, none could be readily defeated in a two-person environment.

Table 9 Ranking of Pressure Sensitive Seals

Pressure-Sensitive Seals Tested	Peel	Shear	Shock	Solvent	Vibration	Abraision	Handling Durability	Tamper Resistance
Mylar	1	1	1	1	1	1	1	3
Paper	3	2	2	3	3	3	2	2
Vinyl	2	3	3	2	2	2	3	1

8.1.2 Loop Seal Testing Results:

8.1.2.1. Radiation Test Results. All seals passed the test with no visual effects of the radiation testing.

8.1.2.2. Temperature / Humidity Test Results. All loop seals passed the test with no visual effects of testing.

8.1.2.3. Mechanical Drop and Pull Test Results:
Cobra Seal: Passed
Fiber-Lock: Failed
Multi-Lok: Passed

8.1.2.4. Vibration Test Results. All loop seals passed the vibration testing.

8.1.2.5. Drop Test Results. The loop seals showed no adverse effects.

8.1.2.6. Summary. Table 10 shows the resultant ranking of the loop seals tested. Most of these seals could be defeated by the vulnerability analysts if they were allowed an unconstrained environment. However, none could be readily defeated in a two-person environment. We cannot comment further on the higher ranked loop seals because of the sensitivity of their uses and the defeat techniques.

Table 10 Ranking of Loop Seals

Loop Seals Tested	Drop/Pull	Shock	Humidity	Vibration	Handling Durability	Tamper Resistance
High Security						
Cobra II	P	P	P	P	P	1
Fiber-Lock	F	P	P	P	P	2
Nominal Security						
Cable Lock	P	P	P	P	P	1
E-cup	P/F	P	P	P	P	2
Multi-Lok	P	P	P	P	P	3
Griplock	F	P	P	P	P	4
Padlock	P	P	P	P	P	5

8.2 Costs. The cost of the seals is significant in some applications. Table 11 lists the costs of the seals tested. In considering the test results, our conclusions, and the cost of the different seals, it seems clear that the lower cost seals should be the choice under current material surveillance conditions. However, conditions do exist that can economically justify the cost of the more expensive devices. Such conditions include cases where the physical inventory period can be extended significantly by the use of higher security seals or materials are in a tamper-indicating container that is judged to be adequate in less-protected environments.

Table 11 Seal Costs

Type	Per Container	System
Pressure Sensitive	$.19 - $2.70	N/A
Passive Mechanical Loop	$.59 - $3.11	N/A
Passive Fiber Loop	$5 - $28	$600 - $6,000

8.3 Testing Recommendations. In general, we recommend that seals being considered for use at DOE facilities to protect nuclear materials should be tested in a manner similar to the testing reported in this document. The MIL-STD-810D provides a good guide for these tests, and either this standard or something similar should be used to qualify seals for these applications. In summary, the testing should consist of the following:

Environmental testing

1. Temperature
   - Cycled high / low temperature at ambient humidity
   - Cycled high / low temperature at high humidity
2. Temperature shock
3. Humidity
4. Radiation

Mechanical testing

Pressure Sensitive Seals

1. Abrasion
2. Peel
3. Shear
4. Solvent

Loop Seals

1. 5-pound drop
2. 50-pound pull (one minute)

Pressure-Sensitive Seals and Loop Seals

1. Drop shock
2. Vibration

8.4 Seal Useage Recommendations.

8.4.1 Pressure Sensitive Seals. We conclude that all the pressure sensitive seals tested are adequate when used under the current material surveillance conditions. If a facility were not already committed to a particular type of seal, we would recommend serious consideration of a mylar-based seal since they are less prone to damage but are adequate with respect to tamper resistance. More specifically, we conclude that the three new seals tested (Confirm, Security Seal, and WatchWord) are as good, or better, than the seals currently in use and are recommended for consideration by DOE facilities.

8.4.2. Loop Seals. We also conclude that all of these are adequate when used under the current material surveillance conditions and that the higher ranked seals should be seriously considered for use outside such conditions. If a facility were not already committed to a particular type of seal and wanted to utilize a relatively low-cost seal, we would recommend serious consideration of the cable lock seal if the holes for the loop are large enough. For smaller holes, we suggest the E-cup as a good choice.